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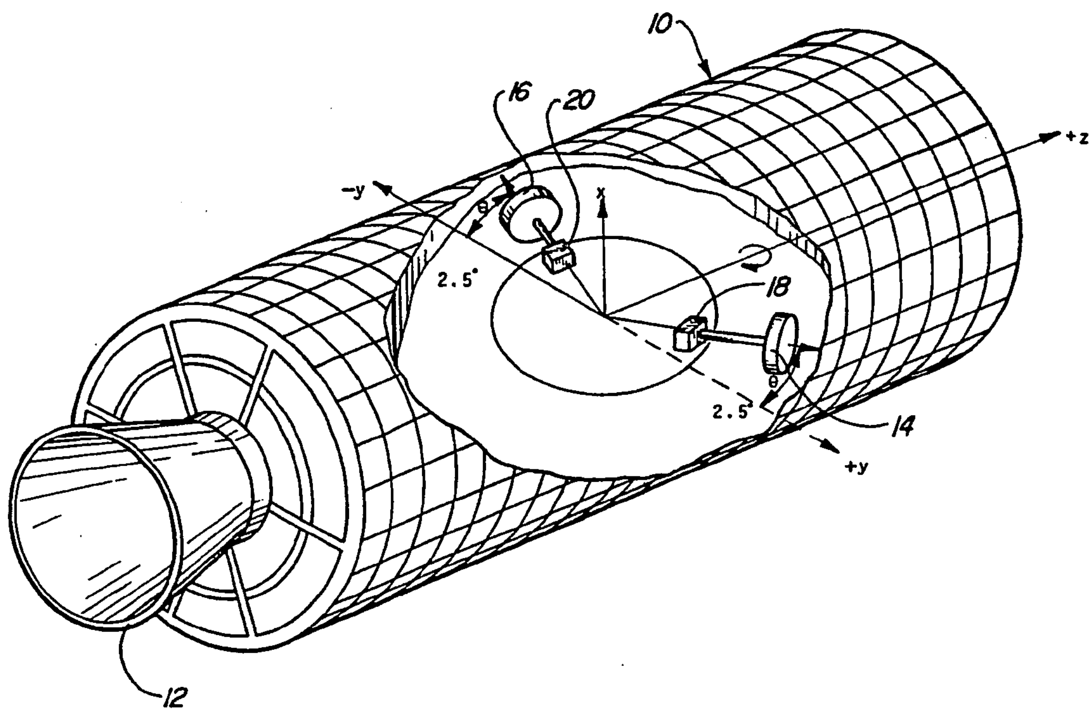
(54) **Spin stabilization via momentum wheels or similar devices.**

(57) A spacecraft (10) incorporating momentum sources such as spinning momentum wheels (14, 16) having momentum vectors or components thereof oriented along the desired axis (z) of rotation of the spacecraft (10). The rotation axis (z) of the spacecraft (10) is nominally any one of the three principle momentum of inertia axes of the body. Proper adjustment of the spin rate of the main body relative to the magnitude of the moment sources angular momentum will insure that the spacecraft (10) will spin about the desired axis (z) in a passively stable way even though the rotational axis is not the principle axis of maximum moment of inertia.



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SPIN STABILIZATION VIA MOMENTUM WHEELS OR SIMILAR DEVICES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a system for stabilizing a spinning spacecraft exposed to destabilizing moments and/or possessing unfavorable mass properties.

2. Description of Related Art

Spin stabilization is the simplest technique for controlling spacecraft attitude for orbiting spacecraft during the launch and orbit injection phases, and the on-station orbiting phase. A spacecraft (or any other generally rigid body) can be characterized as having three principal moment of inertia axes which typically each have a unique moment of inertía value, thus defining a maximum axis, a minimum axis, and an intermediate axis. A continuing problem in spacecraft design is to insure spacecraft stability during rotation. In order to provide stability, spacecraft are spun about either a maximum principal axis which is preferred because it is passively stable, or their minimum principal axis, which provides stability if used with active nutation control systems. Rotation about the intermediate axis is inherently unstable and requires a continuous active thruster control system. Since design constraints in spacecraft design often result in spin being preferred about the intermediate or minimum axes, some form of nutation control system is ordinarily required. Such systems, however, add complexity, cost and weight to the spacecraft.

In view of the foregoing, there is a need to provide a simplified spacecraft stabilization system permitting rotation about moment of inertia axes other than the maximum moment of inertia axis in a passively stable manner.

SUMMARY OF THE INVENTION

In accordance with the present invention, the total angular momentum vector (or a component thereof) of one or more spinning wheels carried by the spacecraft is oriented along the desired rotation axis of the spacecraft. The rotational axis of the spacecraft is nominally any one of the three principal axes. Proper adjustment of the spin rate of the spacecraft relative to the magnitude of the wheels angular momentum insures that the spacecraft will spin about the desired axis in a passively stable way, even though the rotation axis of the spacecraft is not the principal axis of maximum moment of inertia. This invention allows an active spacecraft to spin about any principal axis without requiring sophisticated nutation control systems while alleviating tight design constraints and mass property uncertainty.

BRIEF DESCRIPTION OF THE DRAWING

In the accompany drawing:

FIG. 1 is a pictorial view of a spacecraft including a pair of momentum wheels operating in accordance with this invention to provide passive spacecraft stability.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The physical elements of the system according to the present invention will be described with reference to the figure, which is followed by a description of the theory of operation of the system. FIG. 1 illustrates a representative spacecraft 10 which is cylindrical in shape and has a main thruster 12. Three reference

orthogonal axes are oriented with respect to spacecraft 10 such that the spacecraft is rotating about the z axis. A pair of momentum wheels 14 and 16 are provided which are oriented at an angle (theta) from the y axis. Suitable momentum wheel drive means 18 and 20 are provided for rotating the momentum wheels in a desired direction and speed.

The angle θ is selected to provide a desired component of angular momentum, h_ω , along the spacecraft spin axis as required by the theory in Equations (1) - (8) below.

The theory of operation of the system according to this invention will now be described. A single rigid spinning body can be characterized by three principal moments of inertia axes I_x, I_y, I_z. Assuming the body is spinning about the z axis at a rate ω_z, it can be shown that the rotation is stable if the following inequality is satisfied:

$(I_z-I_x)(I_z-I_y)\,\omega_z^2 > 0$ (1)

Note that rotation about the z axis is stable when it is an axis of maximum or minimum moment of inertia, and unstable when it is an axis of intermediate moment of inertia. Defining $\sigma_x = I_z/I_x$, and $\sigma_y = I_z/I_y$, the condition for rigid body stability can be expressed as:

$\sigma_x>1$ and $\sigma_y>1$ or $\sigma_x<1$ and $\sigma_y<1$ (2)

It can be shown for a "quasi" rigid body such as spacecraft 10 (where energy dissipation occurs and damping is present), that the only stable rotation is when the z axis is an axis of maximum moment of inertia, or:

$\sigma_x>1, \sigma_y>1$ (3)

This is the state corresponding to minimum rotational energy. Defining the "equivalent roll-to-pitch ratio" for an asymmetric body to be σ_e, then:

$(\sigma_e-1)^2 = (\sigma_x-1)(\sigma_y-1)$ (4)

We identify the familiar stability criterion that the "roll-to-pitch" ratio must be greater than 1 for passive stability.

This stability criterion changes significantly if one allows an additional source of momentum on the desired axis of rotation such as provided by momentum wheels 14 and 16. For example, assuming a wheel or combination of wheels providing a component of angular momentum, h_ω, parallel to the z axis, it can be shown that the rotation is stable if the following inequality is satisfied:

$[(I_z-I_x)\omega_z+h_\omega]\,[(I_z-I_y)\omega_z+h_\omega] > 0$ (5)

If one identifies the total spin momentum h_s as:

$h_s = I_z\omega_z+h_\omega$ (6)

and generalizes the inertia ratios σ_x and σ_y to be:

$$\sigma_x = \frac{h_s}{I_x\omega_z}, \quad \sigma_y = \frac{h_s}{I_y\omega_z} \qquad (7)$$

Then Equation (5) implies that a quasi rigid body such as spacecraft 10 with an additional momentum source can have a stable rotation about the z axis which is not required to be the axis of maximum moment of inertia if $\sigma_x>1$ and $\sigma_y>1$. Adjustment of the spin rate of the main body together with the momentum of the additional source can compensate for adverse mass properties and insure stable rotation about the desired axis.

In a specific example of an embodiment of the present invention, a pair of momentum wheels 14 and 16 are oriented with an angle (theta) of 2.5 degrees from the y axis toward the z axis (i.e., 87.5 degrees from the z axis). This value was used since a design of applicant's satelite was capable of angular adjustment of its momentum wheels to this value. Other values for angle theta could be used with equal success and are within the scope of this invention. In order to obtain the desired momentum source along the spin axis, wheels 14 and 16 were spun in opposite directions at their maximum speed. The moment capabilities of wheels 14 and 16 are chosen using the relationship given by:

$$\Delta I = \frac{h_\omega}{\omega_z}, \qquad (8)$$

where ΔI is the effective increase in spacecraft spin moment-of-inertia required to achieve stable spin about the z-axis. Since momentum wheels 14 and 16 combine to provide an appropriate angular momentum

vector component, h_ω, in the direction of desired rotation of spacecraft 10, they insure that the spacecraft will spin about the desired axis in a passively stable mode. This rotational axis of the spacecraft 10 can be any principal axis of intermediate or minimum moment of inertia but will behave as if it were a principal axis of maximum moment of inertia.

Orientation of sufficiently large angular momentum vectors of momentum wheels 14 and 16 in directions opposite the direction of desired rotational axis of the spacecraft can insure that the spacecraft will spin about the desired axis in an actively stable mode. In other words, the rotational axis of the spacecraft can be a principal axis of maximum or intermediate moment of inertia but can be made to behave as if it were a principal axis of minimum moment of inertia. This application could be useful if the desired rotation axis of spacecraft 10 tends to be an axis of minimum moment of inertia but it would be simpler to insure it always remains a minimum axis and employ active nutation control.

While the above description constitutes an embodiment of the present invention, it will be appreciated that the invention is susceptible of modification, variation and change without departing from the proper scope and fair meaning of the accompanying claims. For example, the addition of on-board sensing, software, closed loop control, autonomous or automatic operation, etc. does not change or detract from the basic scope or meaning of this invention.

Claims

1. A stabilization system for a spinning spacecraft (10) defining orthogonally oriented maximum, intermediate, and minimum moment of inertia axes and rotatable about one (z) of said axes, characterized by:
- a momentum source carried by said spacecraft (10) and rotatable to generate a component of angular momentum aligned with the axis (z) of spacecraft rotation which combines with the angular momentum of said spacecraft (10) about said axis (z) of rotation to cause said axis (z) to behave as though it were either a minimum or maximum moment of inertia axis.

2. The system of claim 1, characterized in that said momentum source comprises one or more rotatable wheels (14, 16) carried by said spacecraft (10).

3. The system of claim 1, characterized in that said momentum source comprises a pair of momentum wheels (14, 16) whose angular momentum may be oriented such that said angular momentum from each of said momentum wheels (14, 16) makes an angle Θ relative to an axis (y) perpendicular to said axis (z) of rotation.

4. A stabilization system for a spinning spacecraft (10) defining orthogonally oriented maximum, intermediate, and minimum moment of inertia axes and rotatable about one of said axes (z), characterized by:
- a pair of momentum wheels (14, 16) rotatable about axes lying in a plane common with said axis (z) of rotation and generating angular momentum aligned with said axis (z) of rotation which combine with the angular momentum of said spacecraft (10) about said axis (z) of rotation to cause said axis (z) to behave as though it were a minimum or maximum moment of inertia axis.

5. The system of any of claims 1 through 4, characterized in that said spacecraft (10) is rotated about said minimum or intermediate moment of inertia axis and said momentum source combined with the angular momentum of said spacecraft (10) about said axis (z) of rotation causes said axis (z) of rotation to behave as so it were a maximum moment of inertia axis.

6. The system of any of claims 1 through 4, characterized in that said spacecraft (10) is rotated about said maximum or intermediate moment of inertia axis and said momentum source combined with the angular momentum of said spacecraft (10) about said axis (z) of rotation causes said axis (z) of rotation to behave as though it were a minimum moment of inertia axis.

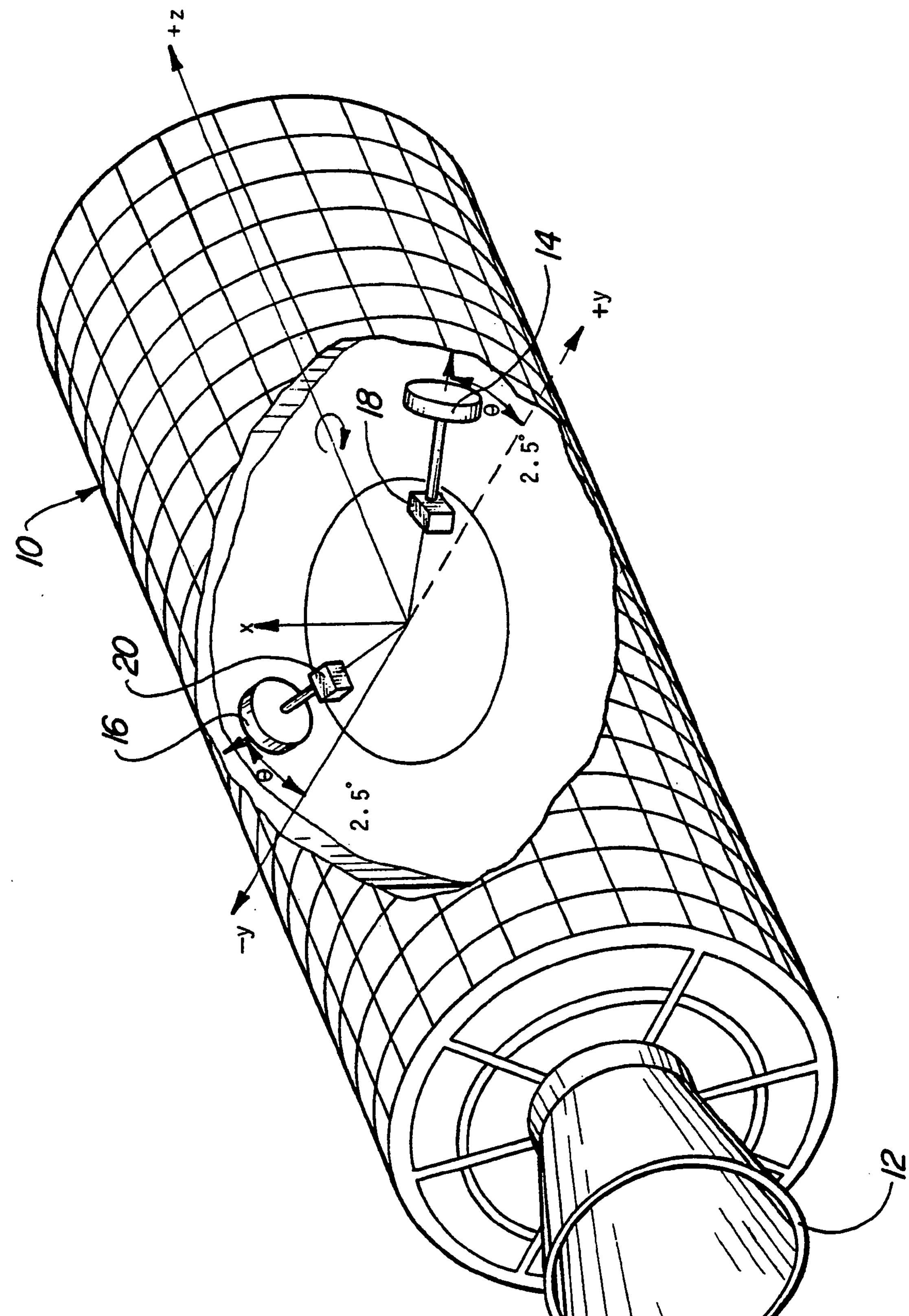
7. The system of any of claims 4 through 6, characterized in that said momentum wheel axes form an angle of Θ degrees from said axis (z) of rotation, the angle Θ being consistent with producing angular momentum components along said axis (z) of rotation.

8. A method of stabilizing a spinning spacecraft (10) about either its maximum, intermediate or minimum moment of inertia axis, characterized by the steps of:
- providing a momentum source in the form of one or more momentum wheels (14, 16) carried by said spacecraft (10) and oriented to provide a momentum component along the axis (z) of rotation of said spacecraft (10),
- spinning said spacecraft (10) about said axis (z) of rotation, and
- spinning said one or more momentum sheels (14, 16) to generate said momentum component such that

the total momentum of said spacecraft (10) about said axis (z) of rotation causes said spacecraft (10) to behave as though said axis of rotation (z) corresponds to either its minimum or maximum moment of inertia axis.

9. The method of claim 8, characterized in that said axis (z) of rotation corresponds to the intermediate or minimum moment of inertia axis of said spacecraft (10) when said momentum wheels (14, 16) are not spinning, and said spinning of said wheel (14, 16) causes said axis (z) of rotation to behave as though said axis (z) of rotation were the spacecraft (10) maximum moment of inertia axis.

10. The method of claim 8, characterized in that said axis (z) of rotation corresponds to the intermediate or maximum moment of inertia axis of said spacecraft (10) when said momentum wheels (14, 16) are not spinning, and said spinning of said wheels (14, 16) causes said axis (z) of rotation to behave as though said axis (z) of rotation were the spacecraft (10) minimum moment of inertia axis.


+z
14
+y
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2.5°
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16
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2.5°
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12

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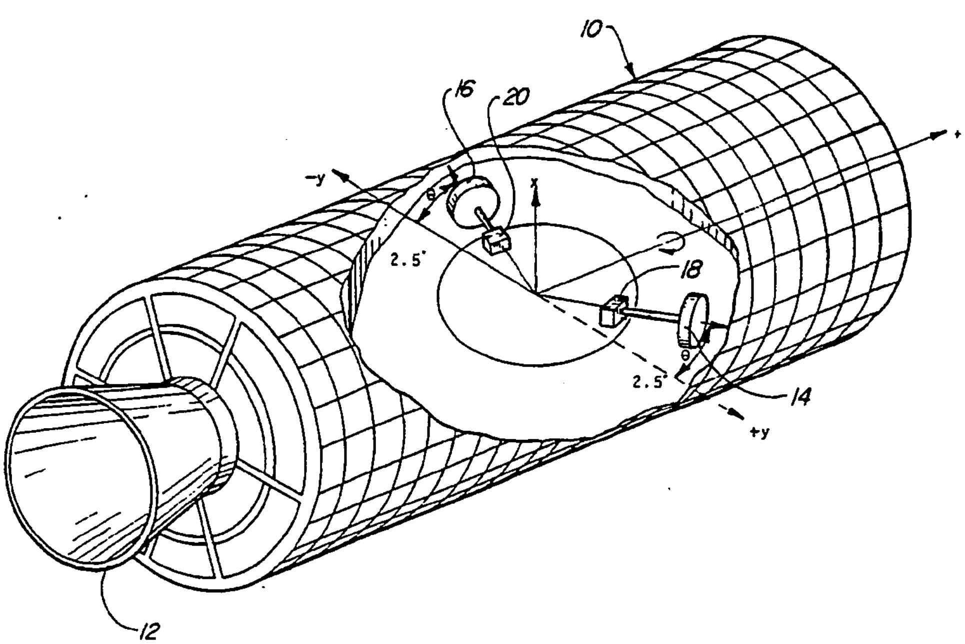

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EUROPEAN SEARCH REPORT

Application Number

EP 89 12 2118

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-4275861 (HUBERT) * column 2, lines 47 - 55 * * column 3, lines 35 - 45 * * column 4, lines 56 - 66 * * column 5, lines 46 - 53 * * column 6, line 60 - column 7, line 7 * * column 10, lines 4 - 65 * * column 11, lines 1 - 16 * * column 13, lines 3 - 49 * * figures * ----	1-10	B64G1/28
A	FR-A-2369612 (MATRA) * page 1, lines 36 - 38 * * page 2, line 24 - page 3, line 1 * * page 5, lines 5 - 12 * * figures * -----	1-10	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			B64G B64C G05D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 AUGUST 1990	ESTRELA Y CALPE J.

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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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E : earlier patent document, but published on, or after the filing date
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